

PHENIX 実験における 多粒子生成の二重ヘリシティ非対称度の測定

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Introduction

- Nucleon spin problem (EMC 1988), gluon polarization in the proton Δg

$$\frac{1}{2}_{\text{proton}} = \frac{1}{2} \sum_q \Delta q + \Delta g + L_{q,g}$$

- reactions accessible to Δg in p+p collision ... jet, inclusive π^0 , direct γ , etc.

- Double helicity asymmetry (A_{LL}) in jet production

$$A_{LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}, \quad R \equiv \frac{L_{++}}{L_{+-}}$$

- A_{LL} has information on Δg

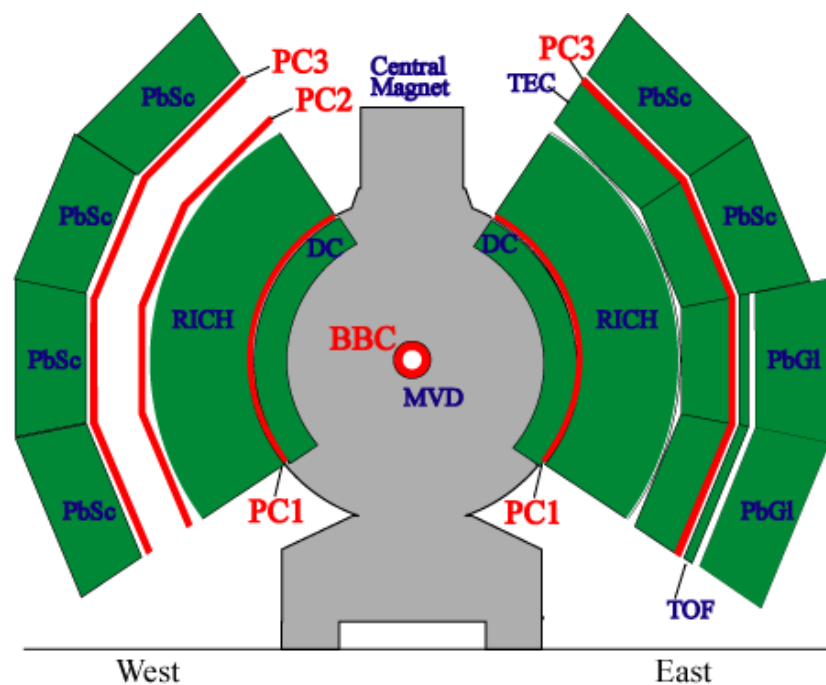
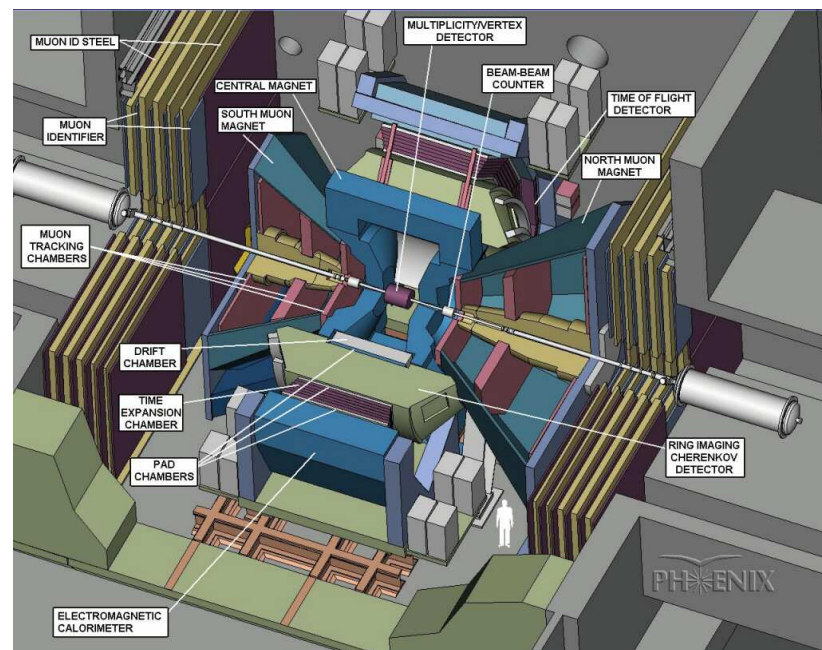
- $g+g$ and $q+g$ reactions are dominant in mid- p_T jet production

- for $gg \rightarrow gg$ reaction, $A_{LL}^{gg \rightarrow gg} = \int dx_1 dx_2 \frac{\Delta g(x_1)}{g(x_1)} \cdot \frac{\Delta g(x_2)}{g(x_2)} \cdot \hat{a}_{LL}^{gg \rightarrow gg}$

- Measurement of multi-particle as a part of jet with PHENIX Central Arm ($\Delta\phi = 90^\circ \times 2$, $|\eta| < 0.35$)

Experimental Setup – PHENIX@RHIC

- Longitudinally polarized proton-proton collision at $\sqrt{s} = 200$ GeV at RHIC
 - Run 2005, $L = 2.2 \text{ pb}^{-1}$, $P = 46\%$
- PHENIX Central Arms: $\Delta\phi = 90^\circ \times 2$, $|\eta| < 0.35$
- Event selection
 - $p_T(\text{photon}) > 2 \text{ GeV}/c$ (offline trigger)
- Particle selection
 - photon: detected with PbGl & PbSc EMCal
 - $p_T > 0.4 \text{ GeV}/c$
 - elemag shower shape cut
 - veto of charged particle
 - charged particle: detected with Drift Chamber & Pad Chamber 1
 - $0.4 < p_T < 4.0 \text{ GeV}/c$
 - track quality cut

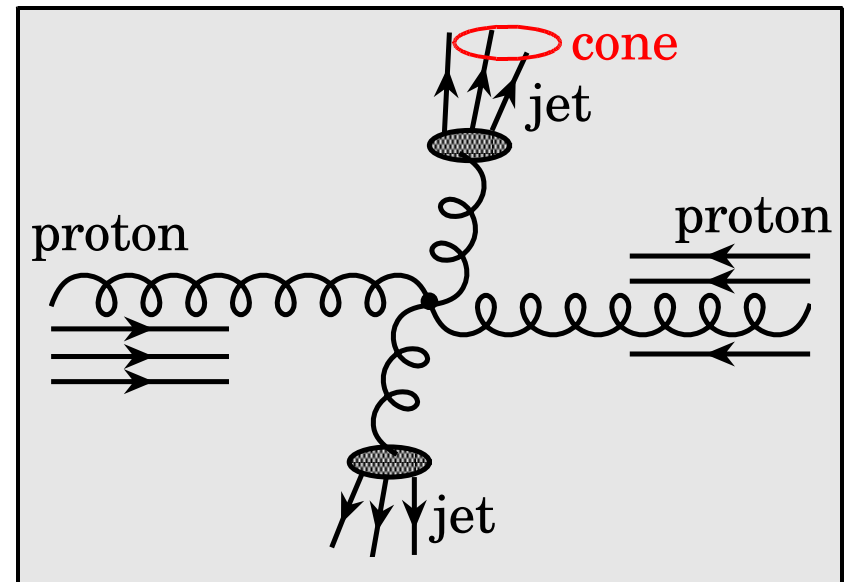


Methods of Multi-particle Measurement

■ Particle clustering with cone

- photons ($p_T > 0.4 \text{ GeV}/c$) and charged particles ($0.4 < p_T < 4.0 \text{ GeV}/c$) with offline high- p_T ($> 2.0 \text{ GeV}/c$) photon trigger
- make cones by using all particles as seed
 - cone radius $R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.3$
 - cone momentum = vector sum of momenta of particles in the cone
 - cone axis = direction of cone momentum (dir. of seed particle at first)
 - iterate above until cone axis becomes stable
- use cone with highest p_T^{cone} in each event

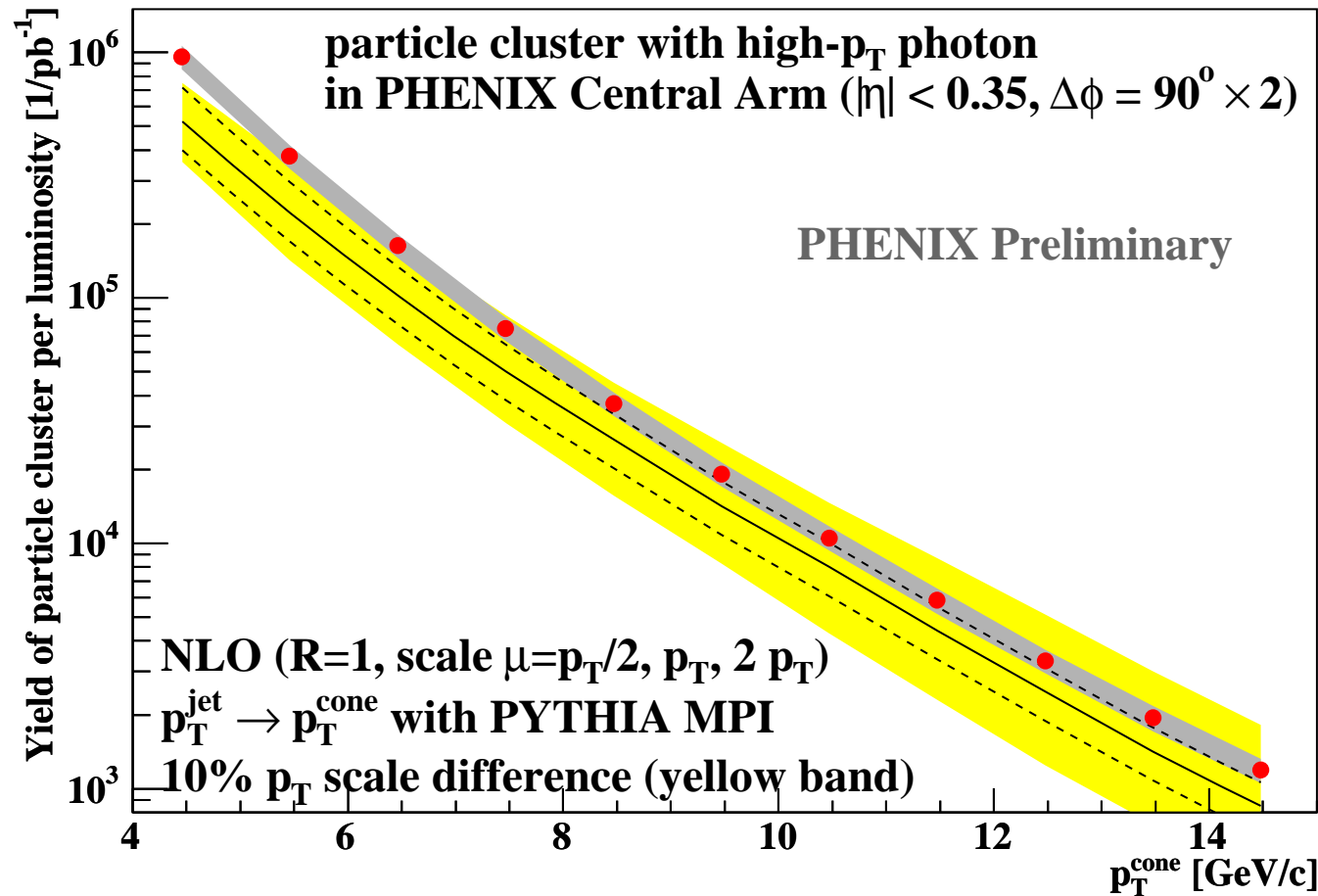
$$p_T^{\text{cone}} \equiv \left| \sum_{i \text{ in cone}} \vec{p}_{Ti} \right|$$



Results – Yield of Particle Cluster per Lumi.

- Purpose: evaluate p_T scale uncertainty on A_{LL} measurement
 - due to the difference in p_T definition between measurement and theory calculation
 - normally there exists $>10\%$ p_T scale uncertainty
 - confirm this uncertainty by evaluating a kind of cross section
- Real data
$$y^{icone} \equiv \frac{C_{\text{corr}}}{f_{\text{BBC}}} \cdot \frac{N_{\text{cone+ph}}^{icone}}{L}$$
 - $C_{\text{corr}} / f_{\text{BBC}}$... correction factor for the yield loss due to trigger efficiencies (high- p_T photon trigger & BBC trigger)
 - $N_{\text{cone+ph}}$... yield of cone+high- p_T -photon events
 - L ... luminosity (2.2 pb^{-1})
- Jet cross section by NLO theory calculation was converted into y^{icone} by using PYTHIA MPI (Multi-Parton Interaction tune) and GEANT simulations

Results – Yield of Particle Cluster per Lumi.



main systematic errors
on real data

luminosity	10%
EMCal ene. scale	5~6%
track mom. scale	0~3%

- slope by NLO+PYTHIA matches with real data over 3 orders of magnitude
- 10% p_T scale difference makes ~50% variation on yield
 - this variation covers the distance between real data and NLO+PYTHIA
- 10% p_T scale uncertainty was assigned to A_{LL} curve

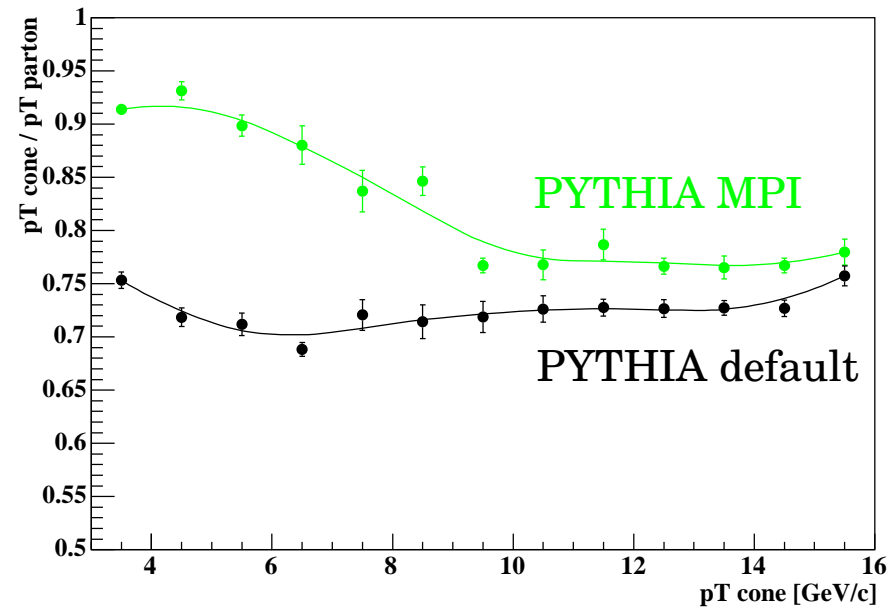
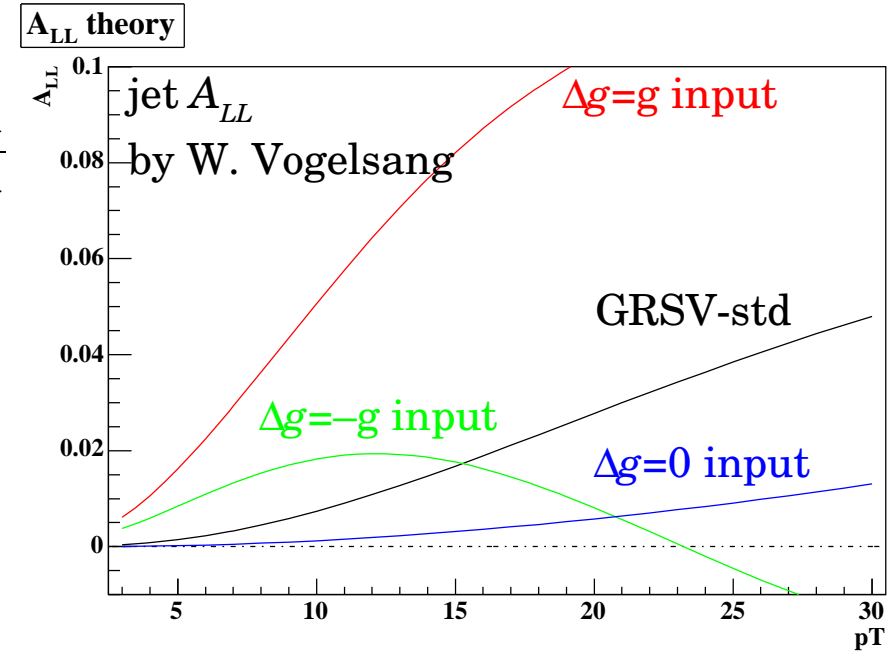
Results – Multi-particle A_{LL}

- A_{LL} was measured as a function of p_T^{cone}

$$A_{LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_B P_Y} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}, \quad R \equiv \frac{L_{++}}{L_{+-}}$$

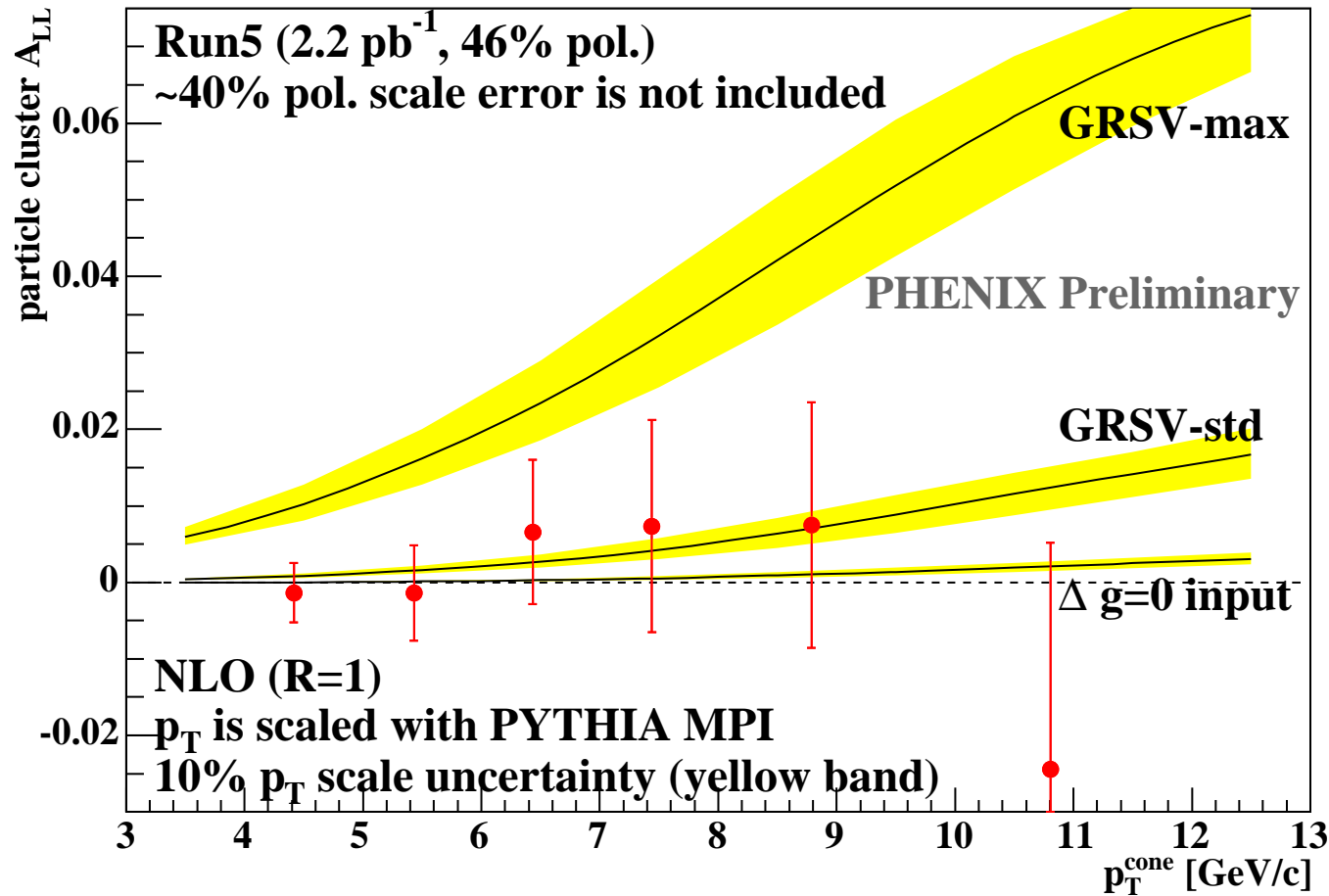
- Theory predictions

- jet A_{LL} in PHENIX Central Arm acceptance ($|\eta| < 0.35$)
- the ratio $p_T^{\text{cone}}/p_T^{\text{jet}}$ was evaluated with PYTHIA MPI + GEANT simulations
- p_T^{jet} in theory calculation was scaled to p_T^{cone} by ratios estimated with PYTHIA+GEANT



Results – Multi-particle A_{LL}

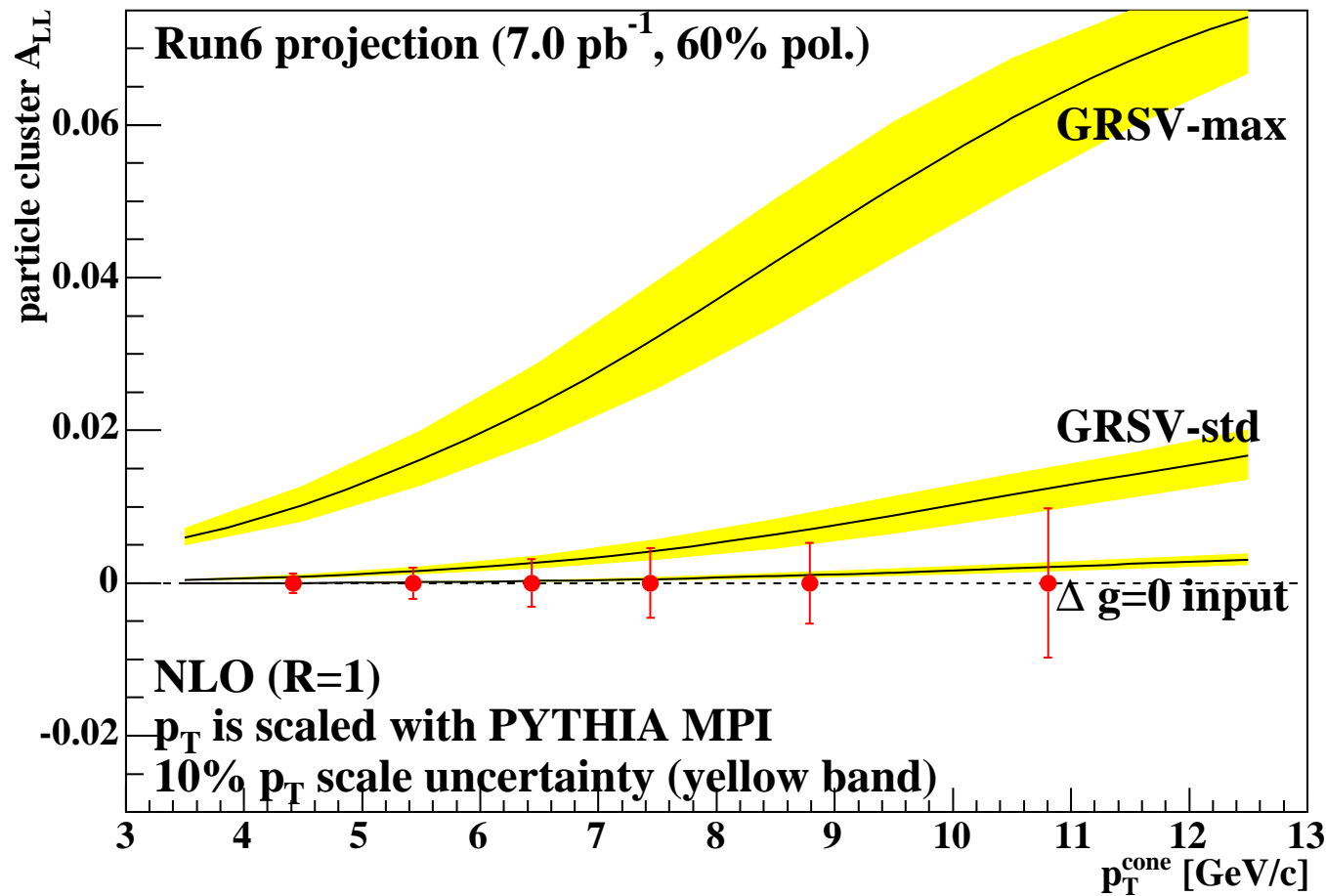
- PHENIX Run5pp ($L = 2.2 \text{ pb}^{-1}$, $P = 46\%$) result



- GRSV-max was excluded (zero C.L.) with this result
- GRSV-std and $\Delta g=0$ input have a similar C.L.

Results – Multi-particle A_{LL}

- PHENIX Run6pp ($L = 7.0 \text{ pb}^{-1}$, $P = 60\%$) projection



- statistical error will reach the size of GRSV-std

Conclusion

- Nucleon spin problem (EMC 1988), gluon polarization in the proton Δg
- Longitudinally polarized proton-proton collisions at $\sqrt{s} = 200$ GeV at RHIC
 - Run 2005, $L = 2.2 \text{ pb}^{-1}$, $P = 46\%$
- Multi-particle measurement as a part of jet with PHENIX Central Arm
 - photons and charged particles with high- p_T photon
 - particle clustering with cone method
- Multi-particle A_{LL} has been measured
 - 10% p_T scale uncertainty
 - theory predictions scaled from p_T^{jet} to p_T^{cone} with PYTHIA MPI
 - GRSV-max was excluded, GRSV-std and $\Delta g=0$ input have a similar C.L.
 - statistical error with Run6 data will reach the size of GRSV-std

Backup...

Yield of Particle Cluster per Lumi.

■ Real data

$$y^{icone} \equiv \frac{C_{\text{corr}}}{f_{\text{BBC}}} \cdot \frac{N_{\text{cone+ph}}^{icone}}{L}$$

- $C_{\text{corr}} / f_{\text{BBC}}$... correction factor for the yield loss due to trigger efficiencies (high- p_T photon trigger & BBC trigger)
- $N_{\text{cone+ph}}$... yield of cone+high- p_T -photon events
- L ... luminosity (2.2 pb⁻¹)

■ NLO theory + PYTHIA

$$y^{icone} = \sum_{ijet} f_{ijet}^{icone} \cdot \epsilon_{\text{trig+acc}}^{ijet} \cdot N_{\text{theo}}^{ijet}$$

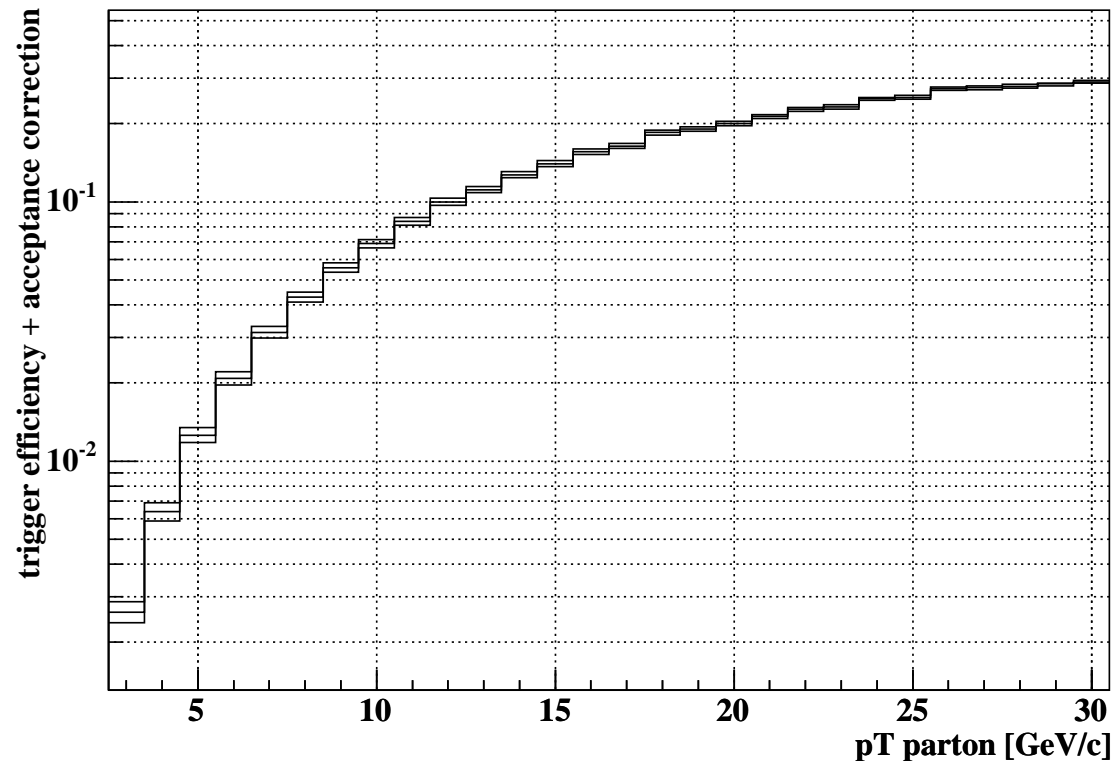
- PYTHIA with Multi-Parton Interaction (MPI) tune
 - PYTHIA MPI agrees with real data in terms of event shape (thrust in PHENIX Central Arm, particle multiplicity, and p_T density in $\Delta\phi$)
- N_{theo}^{ijet} ... jet yield per luminosity calculated from NLO jet cross section
- $\epsilon_{\text{trig+acc}}^{ijet}$... the prob. that a trigger photon exists + jet acceptance corr.
- f_{ijet}^{icone} ... the prob. that an event with p_T^{jet} in $ijet$ bin makes p_T^{cone} in $icone$ bin

Yield of Particle Cluster per Lumi.

- $\epsilon_{\text{trig+acc}}^{ijet}$ in NLO+PYTHIA calculation ... the prob. that a trigger photon exists + jet acceptance corr.

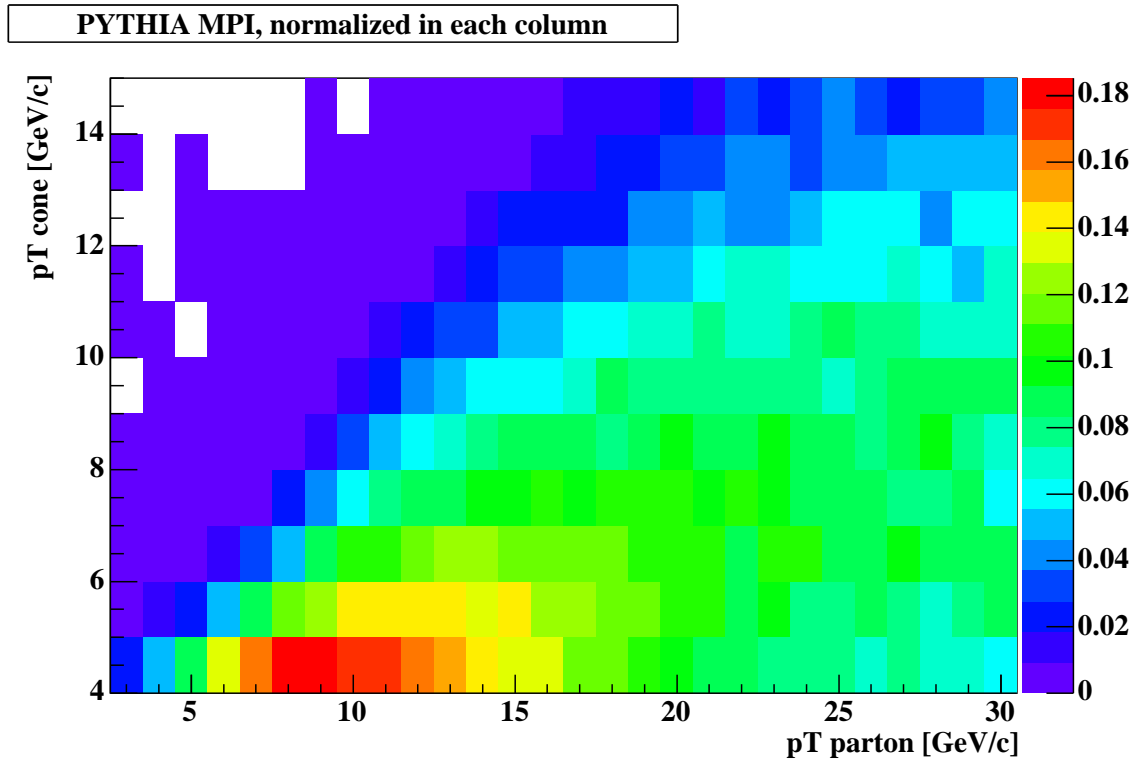
$$\epsilon = \frac{p_T^{\text{ph}} > 2.0 \ \&\& \ \{\eta_{\text{ph}} \text{ and } \phi_{\text{ph}} \text{ in EMCal acceptance}\}}{|\eta_{\text{jet}}| < 0.35}$$

- EMCal acceptance ... $\Delta\eta = 0.7$ and $\Delta\phi^{\text{sector}} = 0.34$ for PbSc and 0.32 for PbGl (two towers from sector edges were not included)
- it was estimated with PYTHIA MPI



Yield of Particle Cluster per Lumi.

- f_{ijet}^{icone} in NLO+PYTHIA calculation ... the prob. that an event with p_T^{jet} in $ijet$ bin makes p_T^{cone} in $icone$ bin
- it was estimated with PYTHIA MPI + PISA



- this $p_T^{jet} \rightarrow p_T^{cone}$ folding used a range of $2.5 < p_T^{jet} < 30.5$ GeV/c, where N_{theo} was available. The contributions from the outside of the p_T^{jet} range to each p_T^{cone} bin was not included. According to PYTHIA, it was 6% at the lowest p_T^{cone} bin (from $p_T^{jet} < 2.5$) and 4% at the highest p_T^{cone} bin (from $p_T^{jet} > 30.5$).

Simulation Condition

- PYTHIA event generator ... same as Run3 analysis
 - version 6.220
 - high- p_T QCD process (MSEL=1)
 - $p_T > 1.5$ GeV/ c (CKIN(3))
 - two PYTHIA settings
 - “PYTHIA default” ... PYTHIA ver. 6.220 default
 - “PYTHIA MPI” ... Multi-Parton-Interaction-tuned setting
 - Rick Field Tune A ... tuned with CDF Run2 data
 - MPI setting is adopted as default from ver. 6.226
 - proton-proton collision at $\sqrt{s} = 200$ GeV
 - CTEQ5L PDF
- PISA detector simulator
 - Run5pp settings
 - the event and particle selections same as real data

Trigger Bias for Fraction of Subprocesses

- Trigger bias effect is evaluated with PYTHIA as the modification of subprocess fractions (qq , qg , gg)
 - gg subprocess are suppressed by trigger photon requirement at low p_T

